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VI.

CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

XL. — AN INVESTIGATION OF THE EXCURSION OF THE DIAPHRAGM OF A TELEPHONE RECEIVER.

By Charles R. Cross and Arthur N. Mansfield.

Presented May 24, 1892.

In a paper published in these Proceedings,* by Messrs. C. R. Cross and H. E. Hayes, it was shown that with a magneto-telephone receiver the magnitude of the change in the strength of the magnet when a weak current is sent through the coil increases up to a certain limit as the strength of the magnet is increased, and then diminishes, the explanation of this diminution being found in the approach of the diaphragm toward saturation. The effect of varying the thickness of the diaphragm upon the magnitude of this change was also studied, and it was found that within the limits of the experiments the changed strength of the magnet due to the weak current is greater with thin than with thick diaphragms.

From these results it would naturally be inferred (1) that the amplitude of the vibration of the diaphragm of a telephone receiver would at first increase to a maximum, and then diminish, if the strength of the magnet were continually increased; and (2) that, within such range of thickness of diaphragm as would probably be most suitable in practice, a thin diaphragm is preferable to a thicker one.

The subject has also been studied by Mercadier,† by ascertaining the distance at which the beat of a metronome, when transmitted by telephone, just ceased to be audible under different conditions of the receiver as to the thickness of the diaphragm and strength of the polarizing magnet. In Mercadier's experiments the thickness of the diaphragms was varied through a far greater range than in those of Cross and Hayes, but their results are in substantial accordance with his for the same conditions of experiment, although the range of thickness in the diaphragms used by them was probably too small to produce the peculiar alternations of effect noticed by the former observer.

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* Vol. XXV. p. 233, 1890.

† Comptes Rendus, 1889, Vol. CVIII. pp. 735, 797; 1891, Vol. CXII. p. 96.

It seemed to the present writers desirable to verify these conclusions by direct observations upon the motion of the diaphragm itself, and the investigations detailed were undertaken with this end in view. We have thus far considered only the first of the two propositions just stated, leaving the second for future study. The experimental work was completed during the spring of 1891.

As it is very desirable not to have the free motion of the diaphragm interfered with in any way, we decided to make use of the stroboscopic method of observing its vibrations.

The telephone which we employed as a receiver had for its polarizing magnet a bar of Norway iron three fourths of an inch in diameter, and eight inches long, which was surrounded by a magnetizing coil consisting of 2750 turns of No. 18 (B. & S.) copper wire, whose resistance was approximately eight ohms. The line coil surrounding the end of the core was made of No. 36 (B. & S.) copper wire, and had a resistance of 99.5 ohms. The core was capable of being moved longitudinally by means of a screw, so that the distance of its end from the diaphragm could be adjusted. In all of our experiments the distance between the core and diaphragm was kept at $\frac{3}{64}$ of an inch. The strength of the magnet was varied by means of a resistance which altered the current passing through the magnetizing coil.

Since it seemed very doubtful whether the excursion of the diaphragm of the receiver when a current so feeble as that of a telephone was used would be sufficiently great to allow of satisfactory measurement, we decided to employ the alternating current from the secondary of a transformer through whose primary was passed the current from an ordinary alternating current dynamo making 128 complete alternations per second. By the introduction of a suitable wire resistance of variable amount into the secondary circuit, the current flowing in it could be reduced to a convenient strength, so that when the magneto-telephone was placed in a derived circuit running from extreme points on this wire the coils were traversed by a current comparable in magnitude with the ordinary telephone current. By operating with a current thus produced, and passing through the coils of the receiver, we hoped to be able to employ a current somewhat, but not very greatly, larger than the ordinary telephone current, so that we might safely assume that the character of the phenomena observed with the former under the different conditions considered would be substantially the same as those occurring with the latter and weaker current.

The alternating current thus produced, which we will call the "line current," was measured by an electro-dynamometer included in the circuit, and placed between the resistance frame and the telephone coil. This electro-dynamometer was constructed especially for the purpose, and was calibrated in the ordinary manner, by passing a direct current of known and variable strength through its coils, making the usual reversals to eliminate the effect of the earth's magnetism.

The intermittent illumination needed for the purposes of our experiment was furnished by the sparks produced by a Helmholtz tuning-fork interrupter, making 128 complete vibrations per second. At each vibration, when the style broke contact with the mercury in the cup a bright spark was produced. The fork was so placed that this flash should illuminate the field of a microscope placed opposite, and which was focussed upon the end of a style carried by the diaphragm of the receiving telephone. The illumination given by the sparks, especially when concentrated by a lens, was abundantly sufficient to enable the observer to see the style as a silhouette against a bright field. The telephone was so placed that the vibration of the style was in a horizontal direction. When no current passed through the telephone the style was of course seen continuously, on account of the rapid recurrence of the sparks. If the rate of alternation of the alternating current employed is exactly 128 per second, thus coinciding in frequency with the sparks, then when this current is sent through the telephone coil, although the diaphragm will enter into corresponding vibration at the same rate, yet the style carried by it will still seem to be at rest when viewed by the microscope. But if the rates are not exactly the same, then of course the familiar stroboscopic effect will be produced, and the style will appear to be in a state of slow vibration, so that the amplitude of the vibration, if sufficient in amount, can readily be measured by means of a spider-line micrometer.

Using an objective having a focal length of half an inch, and an eye-piece of moderate power, and with a very weak magnet in the telephone, we found no difficulty in producing a perfectly measurable vibration with a current of only 5 milliamperes, while with a current of 29.5 milliamperes the excursion rose to fourteen thousandths of a millimeter.

On passing a current through the magnetizing coil alone, the diaphragm is of course immediately drawn towards the core by a certain fixed amount, depending upon the magnitude of the current. Some measurements were made which show the amount of this deflection with increasing values of the magnetizing current. The results of these are given in Table I. The current is given in milliamperes, the deflection in thousandths of a millimeter.

TABLE I.

Current.	Deflection.
14	0.0
46	1.7
85	6.7
123	16.7
155	29.2
195	45.9
246	80.8
300	130.1
367	200.0
431	272.8
473	297.0
502	330.0
604	335.0

We did not carry the increase of current to a higher value, since the deflection of the diaphragm would have become so great as to carry the style out of the field of view.

A comparison of these results — best seen by plotting them as a curve, which we have not thought it necessary to reproduce here — shows that on increasing the magnetizing current the corresponding permanent deflection increases more and more rapidly in proportion up to a value of about $\frac{3}{10}$ of an ampere, after which the deflection is very closely proportional to the current.

In studying the effect of different degrees of magnetization of the core of the receiver upon the amplitude of the vibration of the diaphragm, our mode of procedure was to pass a known direct current through the magnetizing coil, and to vary the alternating line current through the receiving telephone coil, measuring this current by the electro-dynamometer. The extent of the excursion of the diaphragm for each different current was measured by the spider-line micrometer. The deflections given in the tables are each the mean of five readings. The process described was followed for various values of the magnetizing current, with the results shown in Table II. The figures in the first vertical column indicate the serial number of the measurements; those in the second, the strength of the magnetizing current in milliamperes, to which the strength of the magnet was found to be proportional; the figures in the upper line headed L, the various values of the alternating line current in milliamperes; and the figures in the columns vertically beneath these last, the corresponding amplitude of vibration of the diaphragm in thousandths of a millimeter.

TABLE II.

No.	M	L			
		5.0	12.5	21.0	29.5
1	77	4	7	10	14
2	123	8	14	21	27
3	180	12	23	34	43
4	235	17	28	39	47
5	287	23	47	63	81
6	322	37	76	102	127
7	352	44	86	106	130
8	376	31	71	100	120
9	394	26	68	88	113
10	416	30	60	87	107
11	459	22	40	56	69
12	503	16	30	39	50
13	564	8	17	28	36
14	639	8	12	16	21

The results of a portion of the measurements are shown graphically by the curves in Figure 1. Only series 1, 3, 5, 6, 7, 11, 13, 14, are reproduced, as a greater number would have been likely to render the diagram confused. The abscissas are excursions of the diaphragm in thousandths of a millimeter; the ordinates, the line currents in milliamperes. The several curves are numbered to correspond with the serial numbers in the table.

It will be seen from these results, that, as the strength of the magnet of the telephone increases, the amplitude of the vibration likewise increases up to a certain limit, and then falls off. A comparison of them with a curve representing the magnetization of the magnet as

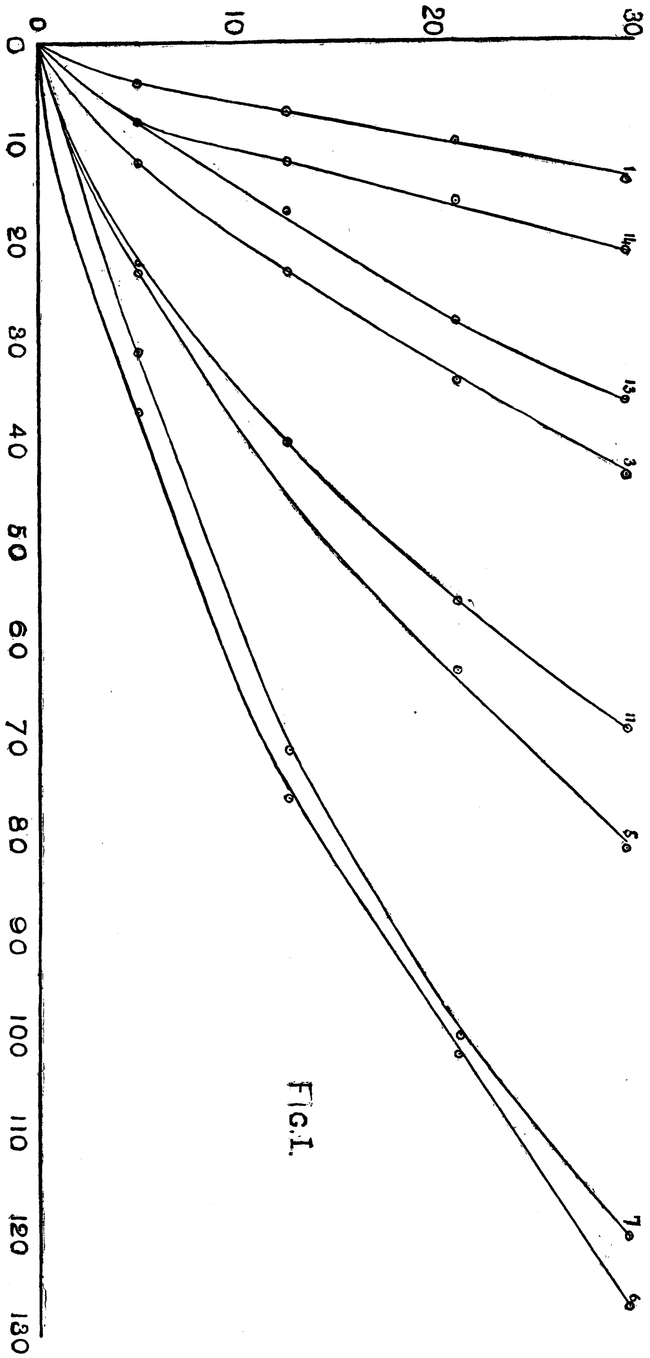

FIG. I.

determined by means of a ballistic galvanometer showed that the maximum motion of the diaphragm with a given value of the alternating line current is reached before the core reaches half-saturation.

An inspection of the curves also makes it plain that in general the amplitude of vibration of the diaphragm increases less rapidly than the current actuating the telephone.

In the experiments previously described the strength of the magnet was kept constant in each series, and the line current was varied. A series of measurements was also made in which the strength of the line current was kept constant, while the strength of the magnetizing current was varied, which shows very clearly the manner in which the amplitude of vibration changes with change in the strength of the magnet. Table III. gives the results obtained. The currents and amplitudes are given in terms of the same units as heretofore.

TABLE III.

Current.	Amplitude.
35	5.5
76	13.6
149	20.5
208	42.3
256	60.8
273	66.0
302	84.5
321	106.5
352	111.5
378	99.8
398	89.6
480	45.4
560	28.0
671	11.6
780	8.5
984	4.0
1142	3.0

Beyond the highest value given in the table, 1142 milliamperes, the excursion seemed to remain almost constant, and of too small a magnitude to be measured readily.

Figure 2 illustrates graphically the results obtained. The amplitudes of vibration are represented by the ordinates of this curve, while the abscissas represent, in terms of an arbitrary unit, the strength of the field at the diaphragm, as obtained from the previously constructed curve of magnetization already referred to.

The figures obtained in these measurements lead to precisely the same conclusion as those already discussed; showing that the amplitude of the vibration of the diaphragm produced by an alternating line current of a given strength increases up to a certain point, and then decreases to a very low value. The point of maximum amplitude is far below the saturation limit of the magnet. It is evident, then, that it is not desirable to use an excessively strong magnet with a magneto-telephone receiver, a result which agrees with the conclusions set forth in both of the papers cited at the beginning of the present article.

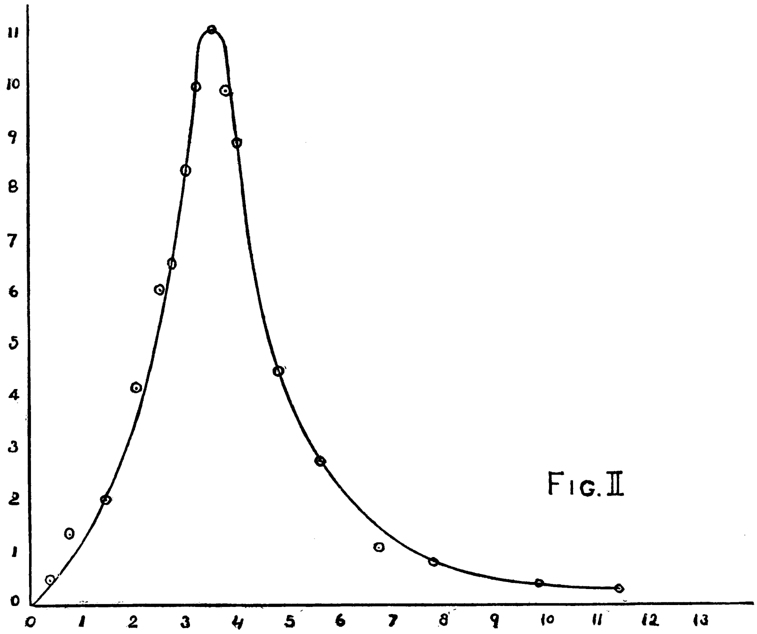

FIG. II

Our observations were not made with the direct intention of determining the absolute magnitude of the excursion of the telephone diaphragm, but they may throw some light upon the subject regarding which the figures given by different observers differ widely. Dr. C. J. Blake,* by inscribing the vibration on a plate of smoked glass, obtained a value of 0.02 mm., and by the use of a micrometer screw with galvanic contact a value of 0.0135 mm. Salet† employed an optical method similar to that employed by Fizeau for measuring the expansion of solids, based upon the variation in position of Newton's rings when these were formed between a light piece of glass carried by the telephone disk and a fixed disk of the same material placed in front of it. The excursion as thus measured was from 0.0002 mm. to 0.0003 mm. Fröhlich[*] measured the excursion by means of a beam of light reflected from a mirror carried by the diaphragm, the beam being cast upon a screen and its motion measured when the receiver was operated. He gives 0.035 mm. as the value of the amplitude of the motion of the diaphragm. Franke[†] employed an optical method similar to that used by Salet, making the assumption that the amplitude of the vibration is proportional to the strength of the current, a supposition, however, which our own results, as given in the preceding pages, do not fully bear out; he concludes that the excursion of the diaphragm for a sound which is just audible is less than 1.2×10^{-6} mm.

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* Jour. Soc. Tel. Eng., 1878, Vol. VII. p. 247.

† Comptes Rendus, 1882, Vol. XCV. p. 178.

Some of these differences are doubtless due to the different transmitters used. Blake employed a box magneto-transmitter, Salet a hand magneto, and Fröhlich a microphone. Also it is very possible that in some of the methods there is more or less interference with the free motion of the diaphragm. The following considerations may therefore be of interest, although they do not lead to absolutely conclusive results.

In all of our experiments, the line current had a value considerably in excess of even a strong telephone current. The weakest value of the line current employed was five milliamperes, while even two milliamperes is a large value for a telephone current produced by a powerful Hunning microphone transmitter. Hence the actual values of the excursions measured by us are much larger than those assumed by the diaphragm of the telephone receiver in practice. We have, however, endeavored to calculate this approximately from the data at hand. It is clear that, if we can obtain the equation of one of the curves in Figure 1, which corresponds to a strength of field of the magnitude employed in the ordinary telephone receiver, we may from this obtain the desired result by substituting in this equation the value of the telephone current. A study of the curves shows that they are all approximately parabolas with the equation $y^2 = mx^n$, n being greater than 2, but the values of m and n are different for the different curves. It was necessary therefore to determine by experiment the strength of the field actually employed in the magneto-receiver. This was done in the following manner. A magneto hand telephone was so placed that it produced a deflection of 45° in the needle of a delicate magnetometer. The telephone was then replaced by the magnet and magnetizing coil used in our experimental apparatus, and the current through the coil was varied until a deflection of 45° was produced in the needle. The current producing this effect was found to be 52 milliamperes. A like experiment being performed with a second telephone, the value of 62 milliamperes was obtained for the magnetizing current. The latter value was chosen, as it came nearest to a strength of current which we had actually used, viz. 77 milliamperes, the lowest magnetizing current that we had employed.

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[*] La Lumière Electrique, 1887, Vol. XXV. p. 180.

[†] Elektrotechnische Zeitschrift, 1890, Vol. XI. p. 288.

By the use of the logarithmic method the equation of this curve was found to be $y^2 = 0.305\ x^{3.26}$, in which y represents the current and x the corresponding amplitude of vibration. Substituting in this equation the value of 2 milliamperes for y, this being the value of a strong telephone current, we obtain the corresponding value of x, which is 2.2; that is, the excursion of the diaphragm of a telephone receiver with the strength of field corresponding to the curve would be 22 ten-thousandths of a millimeter. But the true excursion is probably somewhat less than this, since the strength of field for which the equation holds is somewhat greater than that employed in the telephone, and for a magnetization of this value the deflection would be larger with the stronger field.

It may also be inferred from the preceding results, that so far as sensitiveness is concerned it would be advantageous to employ a stronger magnet in the receiver than is at present used. With the modern microphone transmitter this is not necessary, and upon lines where there is much disturbance it would be harmful, as the proper procedure in such cases is to strengthen the transmitter as much as possible, in which case the receiver may be less sensitive. But if a less strong transmitter is used, as, for example, a magneto-telephone, and upon lines free from disturbance, increased sensitiveness in the receiver is very desirable.

Rogers Laboratory of Physics,
May, 1892.